

Exploring Gender, Computational Making and E-Textiles using the BBC micro:bit

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We present a qualitative study of a Cypriot summer school where we used the BBC micro:bit to examine gender inclusivity in e-textiles. We employed the Computational Making framework to analyze ethnographic data teaching 24 middle school students, aged 10-15. The study contrasts the challenges faced by students using the micro:bit with those from our team's previous similar e-textile studies using the LilyPad Arduino. We pinpoint the BBC micro:bit's limitations from an inclusive design perspective, underscoring the absence of gender-sensitive considerations in its hardware design. The paper presents a critique how upwards of £75 Million were spent deploying the micro:bit without proper user studies of gender equity and e-textiles. We propose design recommendations for future BBC micro:bit versions, advocating for integrating a gender-sensitive participatory design approach to enhance the usability and engagement of computational and creative making with e-textiles for children of all genders.

CCS Concepts: • **Human-centered computing** → **Collaborative and social computing systems and tools**; **Empirical studies in interaction design**; • **Social and professional topics** → **Gender**.

Additional Key Words and Phrases: E-textiles, BBC micro:bit, Computational Thinking, Computational Making, Children

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1 INTRODUCTION

The BBC micro:bit Educational Foundation reports that more than 5 million micro:bits have been distributed to schools, benefiting more than 25 million teachers and students [20]. Considering that each micro:bit kit, including essentials like a USB cable and battery pack, costs around £15 [17], over 75 million pounds have been spent on this technology. As there is a known gender gap of girls in STEM [1, 9], the BBC micro:bit, a programmable microcontroller featuring built-in sensors and actuators, was designed to promote greater inclusivity with "particular focus on girls and those from disadvantaged groups" [21]. Rogers et al. [25] describe the design goals of BBC micro:bit as "universally accessible and gender-neutral" [25, p.75]. They further claim that the device "could support social- and discovery-based explorations of electronics and coding while introducing computing concepts that could be readily linked to children's everyday life" [25, p.75]. However, despite this bold claim, and having spent £75 million deploying the micro:bit, we have yet to find a single study that looked at the gender equity of the micro:bit as part of its development process. Given the importance of gender equity in STEM, this is a shocking oversight.

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E-textile projects are often used as a vehicle for teaching computational making [24], as the amalgam of crafts, coding, and circuitry using sensors, actuators, and conductive thread can result in a powerful combination which can be used to motivate children for exploration, creative making, and teaching programming [16, 22]. They are introduced in the official BBC micro:bit User Guide [14, p. 233] as a core functionality of the BBC micro:bit. Additionally, prior research on LilyPads, an Arduino-type microprocessor, demonstrates how e-textiles are compelling for children of all genders to get them interested in STEAM [5, 22, 30]. In a similar vein, when the BBC micro:bit was introduced with its government backing and equity-emphasized promotion, it prompted us to question whether it would serve as a similarly compelling platform for teaching e-textiles across genders. A common criticism of this research is that it assumes girls are inherently interested in e-textiles using BBC micro:bits, which they are concerned is an example of gender essentialism. However, we argue that while not all girls will find the BBC micro:bit a compelling technology, given that e-textiles are presented as a core feature by the Micro:bit Foundation, they warrant research. Furthermore, it is condescending to assume children cannot independently decide if they are interested in e-textiles. The influence of the patriarchy is significant, but it is crucial to recognize that individuals have the agency to make their own choices. People of all genders continue to show interest in fashion, textiles, crafts and arts, and makers need a full range of gendered applications to be supported in STEAM education and relevant technology innovation.

Despite the need for ensuring equitable educational use, prior studies on the BBC micro:bit have not provided detailed or in-depth qualitative descriptions of the best practices for how children engage with the BBC micro:bits in e-textiles. Our study presents an example of one such workshop, documenting both challenges and opportunities in teaching children computational thinking and making skills. The study is based on a workshop with 24 middle school children, aged 10-15, in Cyprus. By using the Computational Making framework, we were able to compare our findings to a similar earlier workshop teaching STEAM skills with LilyPad [30]. This paper contributes by exploring whether the BBC micro:bit is an appropriate tool to teach e-textiles to children of all genders: we seek to explore children's engagement with the e-textiles learning activities in order to gain an understanding of how children encounter difficulties or experience learning opportunities in mastering programming, electronics, and constructing.

2 LITERATURE REVIEW

The BBC micro:bit (Figure 1a) is a small programmable microprocessor, intended for teaching both electronics and programming via a Scratch-style JavaScript. Located along the bottom of the device, there is an edge connector and plated-through-holes (eyelets), which can be used for connecting external electronic components. The plated-through-holes provide access to power, ground, and three general-purpose input/output signals. In addition, these plated-through-holes can be exploited for e-textiles, where the thread works as conductors. Previous research on the BBC micro:bit shows some significant gaps around e-textile projects. Gardner et al. [13] lays out sample e-textile projects. However, research studies of best practices focus on non-textile and less craft-oriented projects [2, 8]. Prior studies (e.g. [16, 30]) emphasize that e-textiles are unique in their appeal to more gender-diverse demographic populations. However, the omission of studies looking at e-textiles and BBC micro:bits is an important gap for research to address.

A range of studies have sought to explore BBC micro:bit's potential for gender equity. For instance, Eriksson et al. [11] discussed their "large-scale national testbed" based in Sweden which included over 37 BBC micro:bit tutorial videos and a discussion of workshops targeting girls including e-textile activities. However, the specifics of the workshop and their findings were not discussed, leaving the gender equity of the BBC micro:bit in question. Videnovik et al. [29] reported findings from their half-day BBC micro:bit workshop in four unspecified countries. However, their gender findings do not reach statistical significance, nor do they discuss engagement with e-textiles. Finally, Henry and Dumas

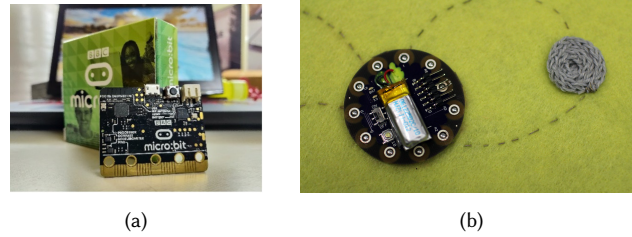


Fig. 1. (a) The BBC micro:bit V1 CC BY-SA 4.0. (b) "LilyPad Simple Snap demo" by Plusea is licensed under CC BY 2.0.

[15] discussed their pilot study teaching BBC micro:bit to children ages 12-14. Similar to Videnovik et al. [29], Henry and Dumas [15] did not present statistically significant results or thick qualitative descriptions of engagement with e-textiles. Both Videnovik et al. [29] and Henry and Dumas [15] reported roughly equal numbers of boys and girls wanting to engage with BBC micro:bit again after their workshop. For example, Videnovik et al. [29] concluded that boys and girls positively endorsed the activity on BBC micro:bit with an average of $M=4.1$ (on a 5-point Likert scale from strongly disagree to strongly agree) on the question *"I would like to learn more about micro:bit"*. Henry and Dumas [15] reported that 67.4% of boys and 60.9% of girls wanted to participate in an additional workshop, suggesting that BBC micro:bit is an equitable tool for engaging with children of all genders.

BBC micro:bit is considered more suitable for teachers and their students, compared with prior microcontrollers, such as LilyPad Arduino and Raspberry Pi. The reasons include (a) low cost; (b) on-board features (e.g. LED matrix display, accelerometer, temperature sensor, compass) that other microcontrollers are not equipped with; (c) various easy-to-connect breakout boards to drive motors, sensors, and electronic bricks; and (d) teaching of high level programming via a Scratch-style JavaScript [11]. However, as argued by Sentance et al. [27], although BBC micro:bit technology itself is often of primary interest, the focus on how technology can be used effectively to support students' learning engagement, accounting for its challenges and opportunities, has received limited attention yet. Indeed, relevant studies in the field have focused on the investigation of teachers' and students' perceptions on the use of BBC micro:bit in the context of workshops [15, 27, 28], or provide reflections and considerations around these efforts [11, 28]. However, none of these studies have provided thick descriptions of how these workshops were organized and enacted. Moreover, none of these studies have provided an in-depth documentation of how the children managed to work with the BBC micro:bits, thus shedding light on the challenges and opportunities in situ. Overall, taking into account the inexpensive and rapid widespread of the BBC micro:bit in educational contexts, it seems important to address how technology can be effectively used for learning, accounting for its challenges and opportunities.

3 THE COMPUTATIONAL MAKING FRAMEWORK

This study adopts the Computational Making framework [24], which has been previously used to understand children's behaviors (programming, electronics, and constructing issues) while participating in e-textile projects with the use of LilyPad Arduino. Computational Making is an extension of the Computational Thinking framework [32], which is "considered best practice for teaching computing and more broadly to solve problems and design systems" [24].

Computational Thinking was proposed to discuss core skills needed for engaging all users with computers, including *analyzing and logically organizing data; identifying, testing and implementing possible solutions; data modeling; data abstractions and simulations; formulating problems in which computers may assist; automating solutions via algorithmic*

thinking; and *generalizing and applying computational thinking* [32]. However, computing “extends beyond the desktop” and thus, when children are engaged in e-textiles activities, they may encounter problems outside of Computational Thinking [24]. This prompted previous studies to propose the Computational Making framework to extend the Computational Thinking framework [24], as the Computational Making framework has been used to examine how STEAM skills develop around LilyPad Arduino activities, beyond those discussed by Computational Thinking [32].

Computational Making focuses on the physical production skills required as technological innovation transitions off the desktop. The framework describes five key challenges to children when engaged with computational making: *aesthetics*, *creativity*, *constructing*, *visualizing multiple representations*, and *understanding materials* [24]. *Aesthetics* is described in instrumental terms, as a way of making technologies “aesthetically pleasing”. While considered “an integral component of computational making”, the authors considered it to hinder children’s creativity. However, they also argued that it can allow children to “make autonomous judgments” as well as to apply nonlinear processes when constructing artifacts. The notion of aesthetics was revised by Rode and Cucuiat [23] in their later work, where they draw on Cubitt [10]’s definition of aesthetics as the mediated experience of time, suggesting that aesthetics is an experience that goes beyond “look and feel” and includes the values and socio-cultural meanings embedded in the technological artifact [3]. *Creativity* is seen as a problem-solving tool as well as a form of skill building that allows for playful interpretive flexibility. *Constructing* is defined as the physical skills required to make artifacts. *Visualizing multiple representations* is viewed as the ability, on behalf of the child, to connect two-dimensional (2D) representations to three-dimensional (3D) artifacts. Finally, *understanding materials* is viewed as the ability to map functionality and outputs onto different materials. As the Computational Making framework has been used to explore STEAM learning with LilyPads, we felt it would allow us a structured basis for understanding if and how the BBC micro:bit could have a similar potential in e-textiles activities.

4 METHOD

In this paper we present a qualitative study of 24 middle school children who took part in a four hour long workshop as part of a summer school activity hosted at a public MakerSpace to learn how to use the BBC micro:bit microprocessor for e-textiles. A four-hour workshop was selected as it fit into the typical timetable of the MakerSpace. The workshop was designed to teach electronic components, circuitry, and basic programming, allowing it to be easily integrated into existing technology-related or science courses. The tasks were embedded in an e-textile project to empower children to engage in creative learning. Four researchers acted as instructing observers, helping out the students throughout and taking notes. The full workshop was also captured on video recording. There were 11 girls (ages 11-15) and 13 boys (ages 10-15). Our research used the BBC micro:bit v1, as this is the only version of the micro:bit available in Cyprus, and it is prohibitively expensive to import them to an island nation.

4.1 Procedures

During the workshop children were asked to create a small stuffed object of their preference equipped with circuitry, including a LED and the BBC micro:bit microprocessor. They were also asked to program it, so as to light up in response to button presses. All children worked in same-gender, self-selected pairs (see Table 1). The researchers engaged in action research teaching, observing and helping children throughout their projects; this role allowed for reflexivity to understand any emergent challenges and opportunities.

Our pre-test survey recorded children’s hobby and class preferences. Art-related activities were listed as favorite activities for 7/11 girls and 2/13 boys. All girls were interested in visual arts, and both boys were interested in music.

Table 1. Participants' Age, Gender, and Project

ID	Gender	Age	Project	ID	Gender	Age	Project
1	M	12	Yellow Star	15	F	15	Yellow Owl
2	M	12		16	F	13	
3	F	12	Globe	17	M	13	Audi Logo
4	F	16		18	M	13	
5	F	12	Pink & Black Cat	19	M	13	Orange Tiger
6	F	11		20	M	12	
9	M	15	Yellow Man	21	M	12	Black TV or Camera
10	M	12		22	M	12	
11	F	11	Red Heart	23	M	12	Orange Cat
12	F	12		24	M	12	
13	F	13	Pineapple	25*	M	13	Unfinished Football Cup
14	F	14		26*	M	10	

Two girls, but no boys, expressed interest in robotics. Gaming was a key area of interest for both genders, with 3/11 girls interested in gaming (one of which explicitly flagging the interest as in board games), and 8/13 boys (three of which were unspecific if they were talking about board or digital games). As far as subject interest in school, Art courses, mostly Design and Technology, which are often taught as a single combined course in Europe, were the favorite for 4/11 girls (one said Music) and 2/13 boys. Computing, Science, and Math were the favorite classes for 5/11 girls and 7/13 boys. Two girls had interests only in non-STEAM subjects such as Language and Music.

We began the session with a hands-on introduction to e-textiles including how to get a button press to trigger an action (on Button command); how to scroll their name across the BBC micro:bit screen; the mapping of zero to off and one to one for the LEDs; how to turn a LED on and off using the BBC micro:bit (the Digital Write command). We also discussed two concepts from Physics: Ohm's Law and the concept of serial versus parallel. Ohm's law tells us that the current going through a resistor is proportional to the voltage going across two points. The first two activities were part of the standard BBC micro:bit onboarding process, and the remaining coding and physical skills were selected as necessary to understand e-textiles. The children practiced to adding LEDs, more current was required and thus more batteries were needed. We also spoke about resistance and how it can be reduced by using two strands of thread when sewing and that both series and parallel circuits are valid ways to connect multiple LEDs to the BBC micro:bit, but only connecting them individually allows for independent control. Finally, we showed sample projects with LEDs.

During the workshop, the children used the BBC micro:bit to make a simple circuit with 1-3 LEDs controlled by the BBC micro:bit, and programmed to be interactive. The children had to create a simple circuit. They were asked to connect the BBC micro:bit to a sewable alligator clip using conductive thread. The alligator clip was connected to one of the signal pins (fingers) labeled 0, 1, and 2, and then sewn to the positive terminal of the LED. A separate piece of thread was used to sew the negative terminal of the LED to the ground pin, thus completing the circuit. The children could elect to connect the LEDs in series or parallel. This was an important decision as it influenced what they could program their project to do. Before moving on with the actual development of their e-textiles artifacts, children were asked to decide and draw a circuit diagram of their planned design on an A4 paper. This intermediate step was crucial, as it enabled children to discuss their designs within their groups and consider the circuitry before implementation. Also, this step allowed the researchers to provide feedback as needed.

4.2 Data collection and analysis

The researchers led the workshop as teachers troubleshooting children’s projects; this allowed for participatory observation which is a well-established ethnographic method within the HCI community [31]. During the workshop we took jottings which later were expanded into detailed fieldnotes [19], supplemented by transcripts from video. In addition, we took photos of the children’s circuitry designs and final e-textiles artifacts. The children’s projects included a yellow star, a globe, a pink cat, a yellow man, a red heart, an Audi logo, a pineapple, a yellow owl, an orange tiger, an orange cat, and a football cup. Figure 2 presents two examples of projects.

The qualitative data were analyzed using a thematic approach [4] guided by the Computational Making framework [24] classifying the data in five main themes: *aesthetics*, *creativity*, *constructing*, *visualizing multiple representations*, and *understanding materials*. Next, we present opportunities and challenges in learning e-textiles with the BBC micro:bits.

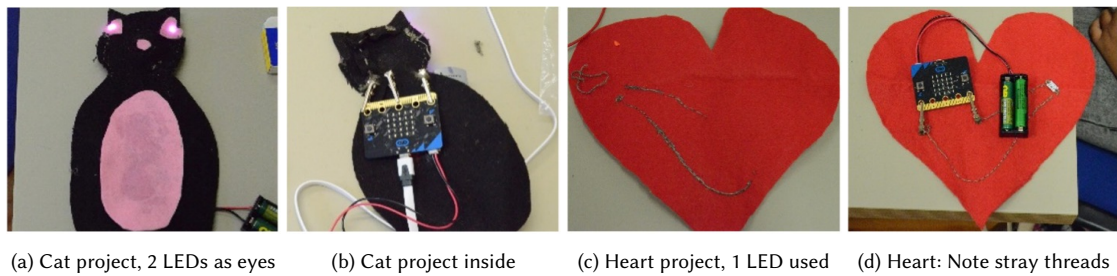


Fig. 2. Examples of student work

5 FINDINGS



Fig. 3. Code from the participant 1&2F who created Yellow Star.

After viewing the sample projects, most of the children had a sense of what to make. Their code was rather simple using the BBC micro:bit Scratch-style MakeCode editor and, for the most part, closely resembled our sample code (Figure 3). We were able to evaluate the final code of 22 of the children. All the codes used Digital Write to control the LEDs primarily in response to button press using our sample code. The makers of the orange tiger (19&20M) were the only ones to add extra code (adding code to display their name on the simultaneous press of buttons A&B). Despite learning how to use the forever loop no child used it for this project. The simplicity of children’s programming

ambitions meant that they had little opportunity to demonstrate various types of computational thinking. Most of the opportunities for practice occurred in relationship to hardware not software, and they were complicated by difficulties produced by constructing and understanding materials. Overall, the e-textiles learning process demonstrated a range of opportunities and challenges, which according to the Computational Making framework were related to *aesthetics*, *creativity*, *constructing*, *visualizing multiple representations*, and *understanding materials*.

5.1 Aesthetics

The children started out by sketching their designs. Most used the LEDs as eyes for animals or as decorative elements for objects such as the heart, pineapple, and football cup. Once they had decided what to do, the children decided on the number and placement of LEDs. The heart used one and others used up to three LEDs. We saw cases where aesthetics was potentially compromised due to technical skills. For instance, in the Pink Cat (5&6F) project glued on a pink belly, the glue rendered the pink transparent, giving a sense of internal organs (Figure 2a). While we do not know what the girls intended in terms of aesthetics, this was in-congruent with the cutesy heart-shaped eyes. The Red Heart (11&12F) makers sewed through the front of their heart, giving the appearance of a silver gash (Figure 2c). While this could have been indicative of a steampunk aesthetic it may also be a signal of children's challenges when implementing their aesthetic visions. At the start of the workshop, as the Orange Tiger makers (19&20M) informed us, they were planning to put stripes on their tiger, but they did not include them at the end. Additionally, we noticed how the delicate shading in their initial drawing was finally replaced by a purely technical circuit drawing.

5.2 Creativity

We showed the children sample projects such as a FIFA logo, a purple cat with light-up eyes, etc as well as sample code. We challenged the children to be creative and use their own ideas for a project that lit up, and we noticed that the children put effort into selecting their projects. This came through browsing the Internet for images as was the case of the designers of the Red Heart (11&12F), and the makers of Yellow Man (25&26M). At the end, we observed the similarity between our projects and theirs, since we had one FIFA logo (25&26M), three cats (5&6F, 19&20M, and 23&24M), and a heart (11&12F). This and the fact children did not program much beyond our sample code, suggests that creativity was hampered by a desire to achieve technical mastery, a problematic tension for STEAM education. However, some artifacts appeared to be entirely original such as the Pineapple (13&14F), the Yellow Man (5&6M), and the Black TV/Camera (21&22M).

On the other hand, individual creativity may have been impacted by the need to compromise to create a shared project, as illustrated in the following excerpt, by 5&6F creators of Pink Cat: *"B: What should we do? A: I have an idea. B: Let's discuss first. A: Kitten. B: Horse. A: Kittens. B: OK! A: Can I show you how I design a kitten?"* This snippet illustrates how each girl had a different vision - one wanted to create a horse the other a kitten. Through negotiation, they arrived at a compromise. Later, girl A showed B her style of drawing a cat. B in turn suggested using hearts for his eyes: *"A: Let me show you what I want us to do. B: Sketch it (on the fabric) but smoothly please so that we can delete everything if we do not like it in the end... A: How about a heart, eyes, and we can add lights. B: Nice idea. A: Do you like?"* Here, we can see the children negotiating among themselves. This negotiation proved fruitfully as both children had a chance to express themselves creatively, and neither had to entirely compromise their aesthetic vision. However, we did see some evidence that children compromised their creativity in some collaborations. For instance, 9&10M were debating on whether their Yellow Man should be green, black, or yellow. This discussion prompted them to play rock, paper, scissors, a children's game sometimes used to help make decisions. Similarly, 25&26M did compromise creative control over the design of the object. B insisted to A *"give him the pencil... I am your better in this (drawing)"*. Thus, we see that children who felt their artistic skills were lacking, often took the back seat in the planning phase, this example only serves to further encourage the skill development of a teammate at the more novice artists' expense.

5.3 Constructing

Throughout the workshop we observed several problems which stemmed from children’s difficulty in manipulating the tools, especially using scissors and threading needles. For example, felt is difficult to cut by children, which is exacerbated by dull children’s scissors that are also used for paper crafts. Figure 4a shows a ragged edge, which did not match the child’s sketch for a smooth line and symmetric face. Likewise, conductive thread is more difficult to work with than regular thread due to it being less smooth; this can be mitigated by applying beeswax, although we may not have made this apparent enough to the children. In this context, we noticed that children struggled to get all the strands of thread through the eye of the needle. See Figure 4a for an example of frayed thread, which resulted in fuzzy balls that were snipped off, but tended to attach to felt as well as short circuits making issues with circuits difficult to debug which can be seen in both Figure 4a and 4b. Poor connections and loose knots often made LEDs flicker, a problem that was also difficult for the children to debug.

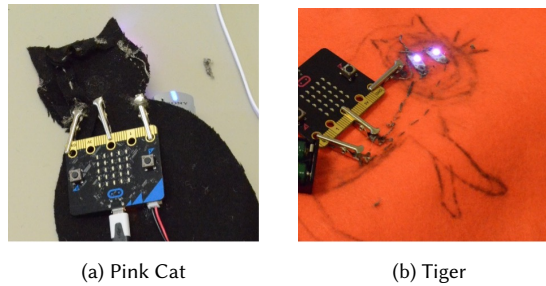


Fig. 4. Close ups of two cats: 4a and 4b. For both notice frayed thread and alligator clip placements.

One construction problem unique to the BBC micro:bit appeared to be sewable alligator clips. The children preferred using a larger embroidery needle as it was easier to thread; however, this needle did not fit through the sewable eye in the alligator clips. This forced them to use smaller needles, which worsened the needle threading problem. Further, while it is recommended in Buechley and Qiu [7]’s “Sew Electric” to pass the needle through the eye of a component several times to create a stable connection, the eyes of the commercially available alligator clips were sized for wiring. It is very difficult to sew them in this fashion. Consequently, the children struggled to create a secure connection, and in the case of Figure 2b you can see how the child tried to mitigate this by stitching around the alligator clip. In turn, this created loose knots causing the alligator clips to flop around.

A second issue related to alligator clips is that they do not form solid connections to the plated-through-holes. As illustrated in both Figure 4a and 4b, this resulted in the alligator clip sliding around such that it was no longer perpendicular to the pin’s finger. In some instances, this shorted the circuits and caused confusion among the children as to why an otherwise correctly constructed and programmed circuit failed to work. In other cases, it triggered unexpected reactions from the fingers that corresponded to buttons and LEDs causing confusion. Further, in the long term the alligator clips run of scratching off the metal plating causing the BBC micro:bit to fail with repeated e-textile, which also is a difficult problem for debugging. This seems to have afforded the children who made the Orange Tiger (see Figure 4b) the possibility of going as far as sewing the alligator clip in across other fingers, though in this case the circuit still lit. These issues resulted in Globe (3&4F) and Pink Cat (5&6F) projects not working. We helping them to discover how removing thread fuzz and tightening stitches and knots, would allow their projects to work properly.

This suggests that the hardware available for e-textiles and BBC micro:bit is not robust enough, and a better means of temporarily attaching the micro:bit is needed. (For comparison, see Figure 1b of the LilyPad.) The LilyPad ecosystem allows the child to use a SimpleSnap to sew to their project, which the LilyPad Arduino, the actual microprocessor, then snaps into. This affords easy removal of the LilyPad microprocessor, enabling e-textile projects to be washed if soiled. Further, it means that the LilyPad microprocessor itself can be easily reused, which encourages experimentation. In our experience, children hate cutting apart their old projects when starting a new one. Most importantly, it acts as a forcing function to ensure solid electrical connections, thereby eliminating the need for painful debugging. These issues need to be eliminated in the micro:bit ecosystem.

5.4 Visualizing multiple representations

Before moving on with the actual development of their e-textile artifacts, children were requested to draw a circuit diagram of their planned design on an A4 paper. Although some perceived this intermediate task as an unpleasant "chore," viewing it as an unnecessary delay in their artifact development, we observed that this step was crucial: it supported children in conceptualizing their planned designs in conjunction with the circuitry and also provided an opportunity for the researchers to offer feedback.

Firstly, this step allowed children to express and visualize their ideas on the paper. As such, it helped children to identify and realize some incongruencies between their prospected designs and their circuitries. We noticed that this visualization, also triggered some interesting discussions between some pairs about circuitry positioning and functionality. At the same time, for us as researchers and observers, these sketches became a "window" into the children's ideas and misconceptions. We therefore initiated several discussions with the student pairs around these visualizations asking them to elaborate further their ideas, questions and concerns around their circuitries. It also helped us to identify student misconceptions, enabling us to conduct small-group discussions or, if the same misconception was observed among several children, discussions with the entire group.

Secondly, during construction, these diagrams guided and supported the children. We saw several instances where the children were advised by their visualizations on how to develop their circuitries. We also noticed some instances where the children they were literally mapping their visualizations on their actual felts and circuitries to make sure that there were not deviations in terms of the circuitries construction and positioning on the felt. Overall, the circuit diagram served as a scaffolding tool which aided in children's artifact construction throughout the process.

5.5 Understanding materials

One of the children's challenges was manipulating the materials to achieve their design goals, as they did not have a complete understanding of material properties. While some materials such as felt and regular thread were familiar to them, others such as conductive thread and BBC micro:bits were new. Consequently, several children treated conductive thread like traditional thread used in handicrafts, tying it off and leaving inch-long tails, which in their specific projects led to short circuits. These short circuits were exacerbated by poor sewing skills and the tendency to create fuzz.

Although felt was a known material to the children, within e-textiles it had new properties. Unlike with cotton broadcloth, where stitches must go from one side to the other, felt allows for invisible stitches by only partially piercing the fabric. This technique would have allowed the Red Heart makers (5&6F) to keep the front of the heart from having a silver scar of stitches (Figure 2c & 2d). These properties even eluded us as workshop organizers. We had mistakenly thought that all felt was the same. This misconception was corrected during an incident where we tried ironing a patch

to insulate crossed traces in a circuit and smelled burning plastic. It revealed that the particular felt was made of plastic fibers, not cotton, causing it to melt instead of behaving as expected.

Last, we did see some instances where children mastered material properties, in particular conductivity. Given the children were struggling with the small hole on the alligator clip, a few wrapped the thread around the clip's body. This showed their correct understanding that increasing contact area reduces resistance in the circuit.

6 DISCUSSION AND CONCLUSIONS

In this section, we highlight our findings on the usability of the BBC micro:bit for e-textiles. We use the computational making [24] to frame its benefits and differences. We particularly focus on evaluating its merits as an e-textile platform relative to the LilyPad Arduino, with attention to any gender differences. We argue that the BBC Micro:bit may not have fully considered the nuanced potential uses in e-textiles design, a field traditionally dominated by female crafters [18]. Its current design features lead students to focus heavily on technical skills and problem-solving, restricting the development of a broader range of skills, such as aesthetics, which are vital for engaging a wider, more gender-diverse audience. Ultimately, this lack of design consideration in the hardware might inadvertently discourage young learners, particularly those who are less accustomed to or comfortable with improvising or adapting to its current physical and functional affordances. And so we conclude that while technically complex with many onboard sensors and actuators, it has many flaws as a tool for teaching e-textiles.

Aesthetics: Aesthetic making is not “about solving problems, about solutions that end a task, about closure” as doing this would not credit the work involved in making [26]. Rather, aesthetics is about the mediated experiences of making over time and the sociocultural meanings and values embedded in them. For instance, as part of this study, in most of the cases, children's aesthetic envisions were compromised during the actual development of the e-textile artifacts. On one hand, this suggests that there is a delicate interplay between design and children's technical skills that need to be developed. On the other hand, we have noticed a tension between aesthetics and children's ability to realize their design impacted by constructing and understanding materials. This tension could possibly have been mitigated if we had opted for a different learning plan. For instance, introducing children to the materials may result in them thinking more critically regarding aesthetics. Likewise, starting with some constructing activities, during which children could be asked to debug and correct incorrect circuits using Fields et al. [12]'s techniques, thereby decreasing the tension between aesthetics and constructing.

Buechley et al. [6] elaborate on the deliberate aesthetic choices made in designing the LilyPad Arduino. The circular layout was chosen to accommodate surface mount components, resulting in larger, easily sewable traces. Comparing this study with earlier research by some of the same authors [24, 30], we observed that the circular design of the LilyPad Arduino facilitates more secure connections, whereas the BBC micro:bit tends to be less stable (see Figure 5). These aesthetic-concerned decisions adversely impact the electrical soundness of the connections, but also frequently result in messy attachments that impact the overall polish of the work.

Creativity: At the outset of the project, we thought that sharing several examples of e-textile projects (e.g. the FIFA logo, a purple cat with light-up eyes, a shooting star, a heart logo, and a rocket ship with flames that lit up) would help the children envision the expected outcome. We had tried to show a range of ideas to avoid gender bias. Although these ideas inspired the children, we also noticed that seeing these samples may have limited their creativity, as is often the case with young learners, many of the children's final artifacts were imitated or very similar to the examples. Reflecting on our findings, this could have been avoided if we had only shared a single indicative artifact or if we had explicitly encouraged children to deviate as much as possible from the example(s). We could also encourage children's creativity

by triggering feelings of competition (e.g. explaining that the most original and unique artifact will be awarded at the end via some voting process). Finally, while working in pairs has been shown to be beneficial for programming, in some groups children’s creativity was suppressed because they had to work collaboratively on a single project. One child’s creative vision was inevitably sacrificed to accommodate joint efforts. Future pedagogical approaches should carefully weigh these trade-offs. Technologically, a key difference between the BBC micro:bit and the LilyPad Arduino is the lesser number of sewable eyes on the micro:bit. This limitation not only reduces the technical complexity but also constrains creativity, as it offers fewer elements for independent control.

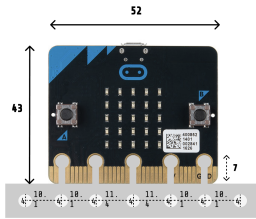


Fig. 5. Prototype of a proposed edge connector for easy attachment of the BBC micro:bit ("Micro:bit Board" by SparkFunElectronics is licensed under CC BY 2.0).

Constructing: Construction skills were influenced by wide gender-based disparities in terms of interest in arts and crafts. These disparities affected technical skills like sewing and drawing, which are integral to the construction process. Beyond the tension observed and already discussed between constructing and aesthetics, we also witnessed various construction problems and difficulties (e.g. easy to thread embroidery needles were too large for the alligator clips’ sewable eyes, or the alligator clips not forming solid connections to the plated-through-holes). In this context, we argue that there is a pressing need for more appropriate e-textile tools and resources to be developed and even accompanying the BBC micro:bit construction kits (e.g. thread that is fray resistant, needles that are compatible with the eyes on the hardware, felt that does not melt). We would

also argue that the alligator clip solution for connecting e-textiles to BBC micro:bit is untenable, and a more robust alternative that allows for easy removal needs to be developed. We propose the creation of an inexpensive sewable BBC micro:bit holder. It would have seven sewable contacts, so the ends of which could be sewn into the garment using regular thread, which allows quick connection and disconnection of the BBC micro:bit (see Figure 5). Instead of using alligator clips to create the traces for P0, P1, P2, P3, and ground, one would be able to sew conductive thread into the edge connector which created five separate independent circuits. Without this type of tool, the LilyPad will remain a more robust solution for e-textile education.

Visualizing multiple representations: Previous work with e-textiles has reported children had difficulty moving between 2D circuit diagrams, connecting the interface with alligator clips, and then sewing it onto a planar surface [24]. Consequently, in our study, we did an activity with children where we showed them a circuit diagram and had them build it, prior to drawing the diagram for their specific e-textile projects. We reminded them to mark the positive and negative aspects of LEDs and, in general, provided feedback. As a consequence, unlike previous research [24], all children were able to create a functioning circuit. We hypothesize that including this additional circuit diagram experience was vital to successful e-textile projects and a useful skill for future 3D making.

Understanding materials: Beyond the tension observed between understanding materials and aesthetics, we also noticed that the lack of children’s understanding of the deployed materials and their properties had several consequences. For instance, we observed several children tying conductive thread in a manner that left inch-long tails, similar to traditional handicraft techniques, which resulted in short circuits. Future workshops could allocate some time, before the actual development of children’s artifacts, during which children would be asked to explore the properties of e-textile materials in more depth (e.g. exploring whether a material is a conductor or insulator, if it is tolerant to high temperatures, its softness, flexibility, etc.). This is crucial to the successful development of children’s artifacts. In

comparison to the LilyPad Arduino, we have observed comparing this study to earlier studies by some the same authors [24, 30] that fabric flows better along the LilyPad Arduino’s circular shape than around the BBC Micro:bits square one.

In summary, the BBC micro:bit, despite its growing popularity, has yet to be thoroughly explored for its effectiveness in supporting learning and engagement among children of all genders. Our findings indicate that the BBC micro:bit, like the LilyPad, has promise for teaching computational making and STEAM skills to children of all genders. Teaching with BBC micro:bit encouraged exploration between the technical and the arts in a way that a pure STEM project would not. The children’s desire to personalize their projects meant that their creative, aesthetic, and material decisions forced them to understand technical constraints in new ways. Gender differences in arts interest prior to the workshop (favorite activities for 7/11 girls but only for 2/13 boys), coupled with a natural tendency for individuals to gravitate towards comfortable skills (e.g. drawing and sewing, as oppose to coding) pose challenges in using micro:bits given to our goal of encouraging a wide range of making skills among all genders.

Our findings highlight opportunities for teaching computational making skills with the BBC micro:bit. Presently, however, difficulties in making solid electrical connections with the micro:bit prompted many children to sew the micro:bit into their projects. By doing so the micro:bit has to be cut out to be reused on a different project or if the e-textile project becomes soiled. Consequently, the micro:bit has some significant limitations as an e-textiles platform relative to the LilyPad. This is somewhat offset only by their inclusion of a wider array of onboard sensors including an accelerometer and indicators, but this is not enough to justify their use for introductory e-textile exercises. We made design suggestions on how to improve the micro:bit ecosystem to address these concerns, and recommend additional participatory design with mixed gender groups.

Given the prior work shows centrality of e-textiles for encouraging girls to learn programming and electronics, we find the absence of user studies examining the micro:bit’s usability for children of all genders deeply concerning. We need to ensure that e-textiles and BBC micro:bits are usable by children of all genders. The fact that approximately £75 million has been invested in an educational technology tool without any published papers validating their gender equity is deeply concerning. It is our hope that BBC micro:bit v3 addresses these issues before its release. We recognize that our population was not especially diverse in various ways, so in our future work, we plan on doing multi-sited ethnography to get a more diverse intersectional population. Regardless, in this paper we have shown the BBC micro:bit does have potential for teaching computational making [24]. We hope that this work will guide further research in this area, including developing a more mature connector ecosystem for e-textiles, and will inspire more critique of relative strengths and weaknesses of the various e-textile ecosystems and encourage more pedagogical research exploring the value of the micro:bit for e-textiles to encourage diverse groups of children to engage in STEAM.

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